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Computer Processing of Multispectral Scanner Data Over Coal Strip Mines

Lockheed Electronics Co, Inc, Las Vegas, NV Remote Sensing Lab

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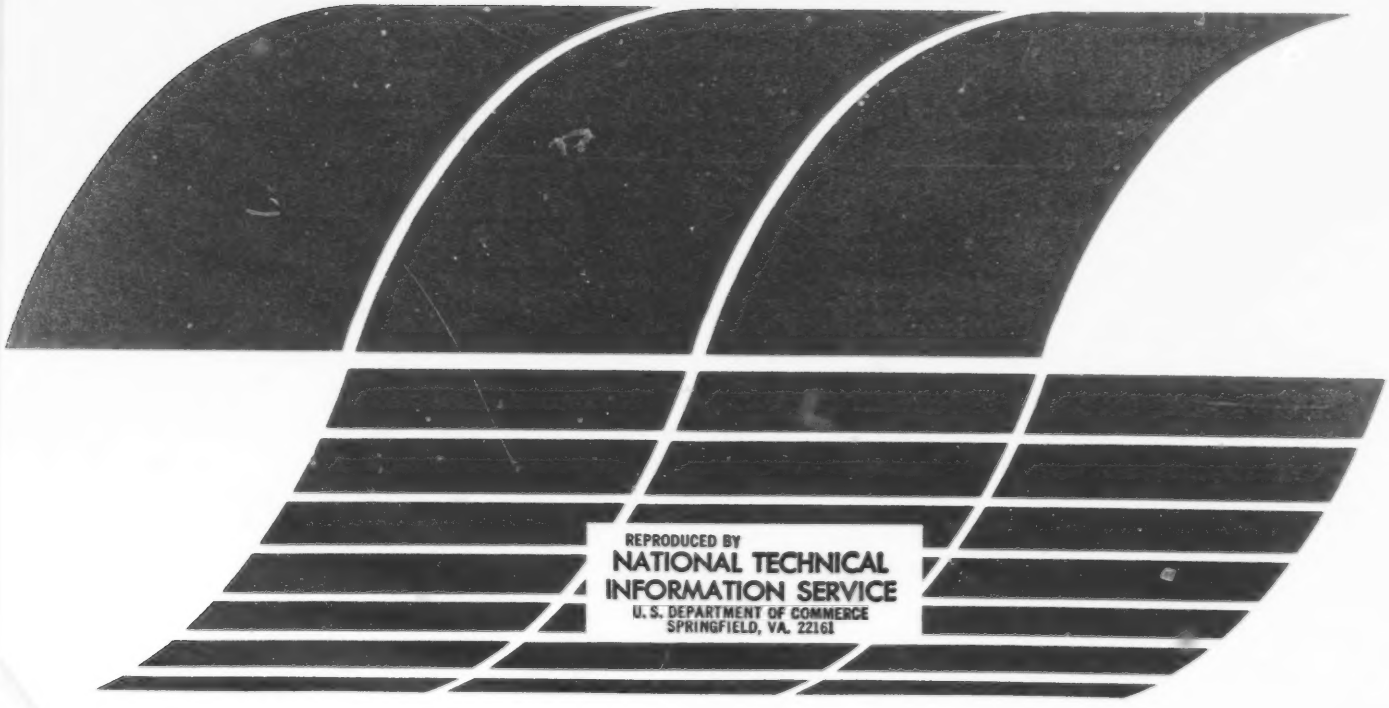

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16. ABSTRACT

Aircraft multispectral scanner data over six coal strip mines in the States of Wyoming, Montana, Colorado, and Arizona were processed on the data analysis minicomputer system using a clustering approach to automatic pattern recognition. The classification results demonstrated that a Level I hierarchy of vegetation, manmade features, and disturbed areas is easily obtained with a minimum expenditure of time.

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COMPUTER PROCESSING OF MULTISPECTRAL SCANNER DATA OVER COAL STRIP MINES

by

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COLOR ILLUSTRATIONS REPRODUCED
IN BLACK AND WHITE

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FOREWORD

Protection of the environment requires effective regulatory actions that are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound, integrated monitoring data base through multidisciplinary, multimedia programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report presents the results of the Phase II operations of the Western Energy Overhead Monitoring Project conducted by the Environmental Monitoring and Support Laboratory-Las Vegas, Nevada. It describes and outlines procedures used to produce Level I land-cover classification maps of selected coal strip mines. These data are then used to assess reclamation efforts and monitor changes on active strip mines in the Western United States.

George B. Morgan
Director
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ABSTRACT

There is little doubt that remote sensing techniques can be effectively applied to the task of monitoring coal strip mine progress and reclamation work. Aircraft multispectral scanner data acquired over six coal strip mines in the States of Wyoming, Montana, Colorado, and Arizona were processed on the Data Analysis System (DAS) using a clustering approach to automatic pattern recognition. The classification results demonstrated that a Level I hierarchy of vegetation features, manmade features, and disturbed areas could be easily obtained with a minimum amount of time. Aside from satisfying a Level I hierarchy, the results may be used as input to other classification approaches to pattern recognition, or they may be incorporated into a data base for planning or for conducting temporal analyses studies.

This report was submitted in partial fulfillment of Contract No. 68-03-2636 by Lockheed Electronics Company, Incorporated, under the sponsorship of the U.S. Environmental Protection Agency.

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SCIENTIFIC NAMES OF VEGETATION IDENTIFIED
IN PHASE II OPERATIONS

Common Name	Genus and Species
Alkali sacatone	Sporobolus airvoides
Blue grama	Bouteloua gracilis
Greasewood	Sarcobatus vermiculatus
Green needlegrass	Stipa viridula
Indian Ricegrass	Oryzopsis hymenoides
Junegrass	Koeleria cristata
Juniper	Juniperus sp.
Mormon tea	Ephedra sp.
Needle-and-threadgrasses	Stipa comata
Pinyon pine	Pinus edulis
Rabbit brush	Shrysothamnus sp.
Sand dropseed	Sporobolus cryptandrus
Sagebrush	Artemisia sp.
Serviceberry	Amelanchier sp.
Snakeweed	Gutierrezia sp.
Wheatgrass	Agropyron sp.
Winterfat	Eurotia lanata

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Sincere thanks are extended to mine personnel at the Decker, Nucla, Dave Johnston, Colstrip, and Black Mesa Coal Strip Mines for providing assistance during ground-truth operations.

INTRODUCTION

The extraction and transportation of coal can be and sometimes is unattractive, but a certain price in environmental damages usually must be paid to obtain the coal required for our standard of living. In the West, coal is extracted by surface mining techniques in which the overburden is removed to expose and allow the extraction of the underlying coal seam. Surface mining is divided into two general types: area mining and contour mining. Area mining is practiced in relatively flat to gently rolling terrain. Contour mining is practiced where deposits occur in hilly or mountainous country.[1]

It has been demonstrated that surface mining can be done responsibly without permanent aesthetic damage to the land and water provided the mining company plans ahead and follows established or recommended guidelines. Technology exists for the effective reclamation of mined lands, and many mining companies are taking full advantage of such technology as evidenced by the reclamation efforts in the West.

The first national attempt to regulate surface mining activities was made by the 95th Congress of the United States when it passed the Surface Mining Control and Reclamation Act of 1977. The purpose of this act is to provide for the cooperation between the Secretary of the Interior and the States with respect to the regulation of surface coal mining operations and the purchase and reclamation of abandoned mines.

In anticipation of the passage of a comprehensive strip mining bill and because of its Congressional charter, the Environmental Protection Agency (EPA) entered into a five-year interagency project with the National Aeronautics and Space Administration (NASA). The purpose of the project is to transfer hardware and software technology for processing remotely sensed digital data from aircraft or satellite platforms to the monitoring of coal strip mine operations in the Western United States.

This project was divided into three phases. Phase I (as reported by Anderson, et al.) was an 18-month task during which time NASA, at its Earth Resources Laboratory (ERL) in Slidell, Louisiana, defined a data collection system for installation in an EPA aircraft located at the Environmental Monitoring and Support Laboratory in Las Vegas, Nevada (EMSL-LV). The Earth

Resources Laboratory was also to process Landsat and aircraft-acquired multispectral scanner data of selected strip mines in the West using basic pattern recognition techniques refined and/or developed at NASA/ERL. Finally, NASA was to build a Data Analysis System and train EPA personnel in its use and maintenance.[2]

Phase II of the joint project was undertaken by the Environmental Monitoring and Support Laboratory Las Vegas. EMSL-LV used the system developed at ERL to monitor selected coal strip mines in 6 Western States and at the same time to develop its own procedure for performing "quick turnaround" land-cover classification maps and acreage statistics for coal strip mines.

Phase III will be the testing phase of the system and techniques in an operational mode, with parallel software development and assistance being provided by NASA/ERL.

Phase II of the joint project was begun in January 1977. During this phase, EMSL-LV used an 11-channel multispectral scanner (MSS) and the Data Analysis System (DAS) computer and its software to monitor selected coal strip mines in the West and Northern Great Plains area. Figure 1 illustrates the general location of the mines within their respective states.

Also, during this time, NASA/ERL (using a similar system) is investigating specific problem areas related to coal strip mines, mine-mouth power plants, and oil shale and geothermal energy sites which require additional research.[2]

This report discusses the results of the phase II operations conducted by EMSL-LV and briefly outlines the techniques employed or developed to obtain the results.

Figure 1. The location of active coal strip mines analyzed in phase II operations.

CONCLUSIONS AND RECOMMENDATIONS

The results of a sequential clustering approach to pattern recognition provided useful Level I land-cover classification maps of active coal strip mines. The map that was produced by the clustering program can also be upgraded to Level II or Level III if the necessary ancillary data (vegetation-type maps, ground-truth data, etc.) are available. As an added feature, the Level I classification map can be used as input to other classification approaches to pattern recognition. These data would facilitate the selection of homogeneous training samples that are required when using the supervised classification approach.

Based on the results of this portion of the EMSL-LV phase II operations it is recommended that:

- Modifications to the clustering algorithm be performed to reduce run time and to accept statistical input parameters as well as a nonrectangular or square field input,

- other available software programs similar to the clustering algorithm available on the EMSL-LV interactive computer be evaluated to determine their utility in classifying coal strip mine areas, and

- use of the sequential clustering algorithm be continued as the "first cut" at land-cover classification of coal strip mine areas.

DATA ACQUISITION

Aircraft multispectral scanner data were collected over the selected coal strip mines in late June, 1977. Data were used because their spectral and spatial resolution would permit computation of very detailed statistics for major land-cover categories.

The Environmental Monitoring and Support Laboratory-Las Vegas subleases a light twin-engine Aero Commander (Figure 2) that is used to conduct special surveys and provide support to ongoing investigations. This aircraft is capable of attaining a maximum altitude of 7,315 meters (24,000 feet) above mean sea level (MSL). Instrumentation aboard the aircraft consists of a metric camera and an 11-channel multispectral scanner. The scanner and the metric camera are used for monitoring coal strip mines and are discussed in the following paragraphs.

MULTISPECTRAL SCANNER

The multispectral scanner (Figure 3) is an airborne system capable of collecting data at altitudes ranging from 500 feet (152.4 meters) to 20,000 feet (6,096m) above ground level. This system is designed to collect and record radiant energy data in the ultraviolet through the thermal infrared portions of the electromagnetic spectrum (see Table 1 for bandwidths).

The scanner has a rotating mirror that scans across the ground scene perpendicular to the line of flight (Figure 4). Radiant energy from the ground surface is reflected through an aperture onto a beam splitter, which diverts the visible radiation (0.38 - 1.10μm) to a 10-channel spectrometer and the thermal infrared radiation (8 - 14μm) to a solid-state detector. Electronic signals from the 11 detectors are digitized and recorded on magnetic tape in a high-density format. The scan rate is synchronized to the aircraft ground speed and altitude, resulting in scan-line contiguity at nadir, thereby avoiding over- or under-scan of the ground scene. The scanner is equipped with internal visible and thermal reference sources, which provide information for calibration of the data. The aircraft sensor tape is processed on the ground-based Data Analysis System (DAS) to display, analyze, and create images of the surveyed scene. These processes will be discussed in greater detail in another section of this report.

Figure 2. Twin-engine Aero Commander used by EPA in support of ongoing investigations and surveillance.

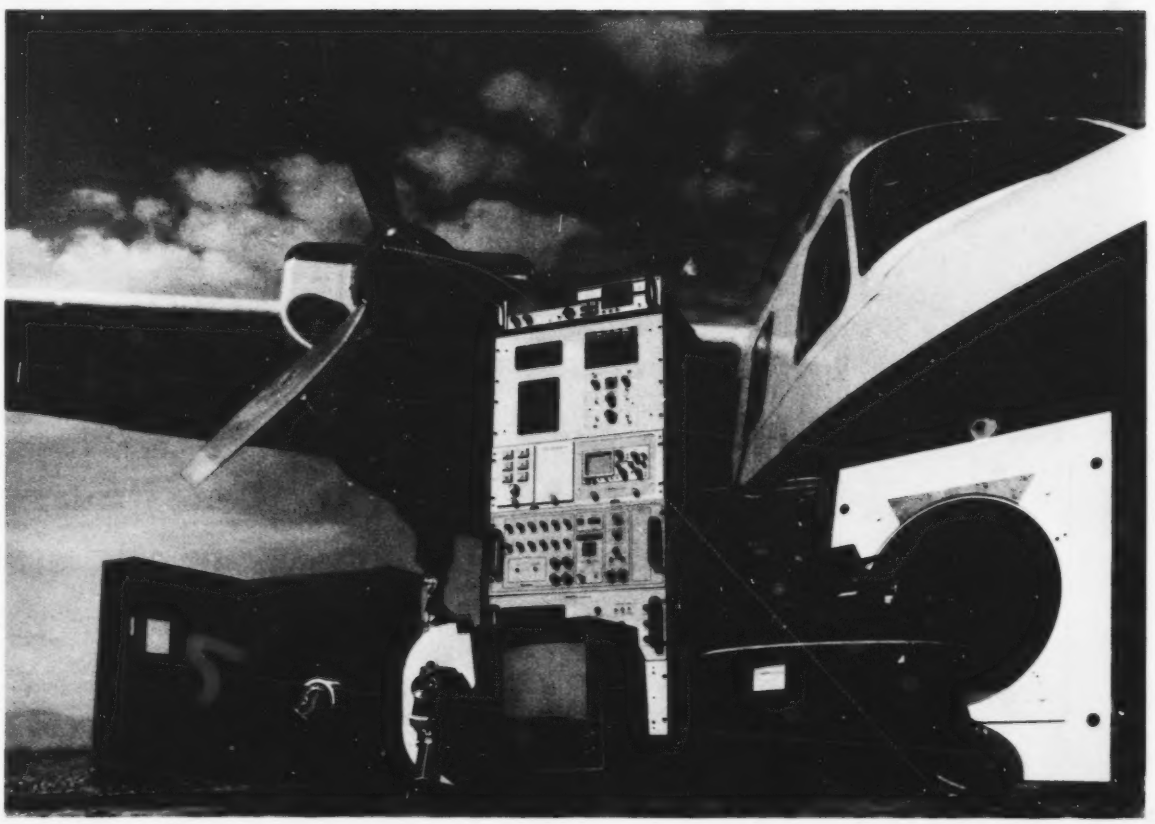

Figure 3. An 11-channel multispectral scanner used by EPA in ongoing investigations.

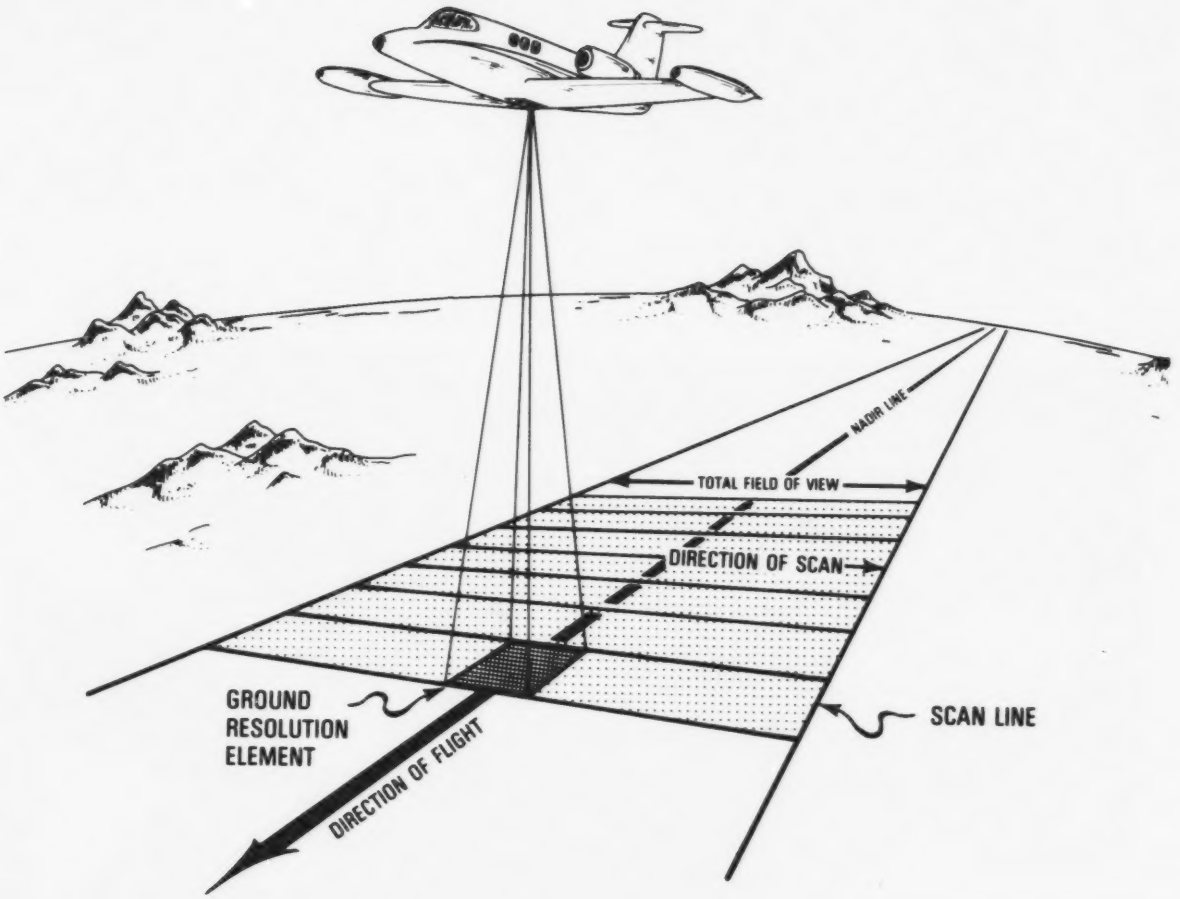

Figure 4. Multispectral scanner imaging characteristics (simplified).

TABLE 1. MSS WAVELENGTH BANDS

Channel	Wavelength Band (μm)	Color/Spectrum
1	0.38 - 0.42	Near Ultraviolet
2	0.42 - 0.45	Blue
3	0.45 - 0.50	Blue
4	0.50 - 0.55	Green
5	0.55 - 0.60	Green
6	0.60 - 0.65	Red
7	0.65 - 0.70	Red
8	0.70 - 0.79	Near Infrared
9	0.80 - 0.89	Near Infrared
10	0.92 - 1.10	Near Infrared
11	8.00 - 14.00	Thermal Infrared

METRIC MAPPING CAMERA

The camera that is part of the instrumentation aboard the aircraft is a 6-inch focal length (15.24-centimeter) metric camera. Its primary use is a ground-coverage documenting camera. The film/filter combinations and exposure techniques are chosen to obtain photographic imagery in the desired spectra.

The following lists the camera specifications:

- Type
  9-inch (22.86cm) square image utilizing a 6-inch (15.24cm) F/5.6 Universal Aviogon lens. Unit has no forward-motion compensation.

- Lens
  Focal Length, 6-inch (15.24cm) nominal, with Waterhouse stops; apertures of F/5.6, 6.8, 8, 11, 16, 22, and 32. View angle 74 degrees.

- Shutter
  Continuous variable rotary, speed from 1/100 to 1/700 second.

- Cycle Interval
  One cycle each 3.5 seconds, maximum rate.

DATA PROCESSING

Data processing begins after the scanner data have been recorded on a high density digital tape (HDDT) and returned to the laboratory. The aircraft-acquired multispectral scanner data must be converted into another format because conventional computers, such as the Data Analysis System, cannot read the data format produced by an aircraft multispectral scanner. Therefore, a special device has been designed to convert aircraft multispectral scanner data into the format expected by conventional computers. This reformatting procedure has been termed decommutation and is made in the HDDT or pulse-coded-modulation (PCM) front-end hardware (Figure 5). Following the decommutation operation, standard data processing techniques are applied to all other functions (Figure 6) in order to produce a classified image and to generate the required acreage statistics.[3]

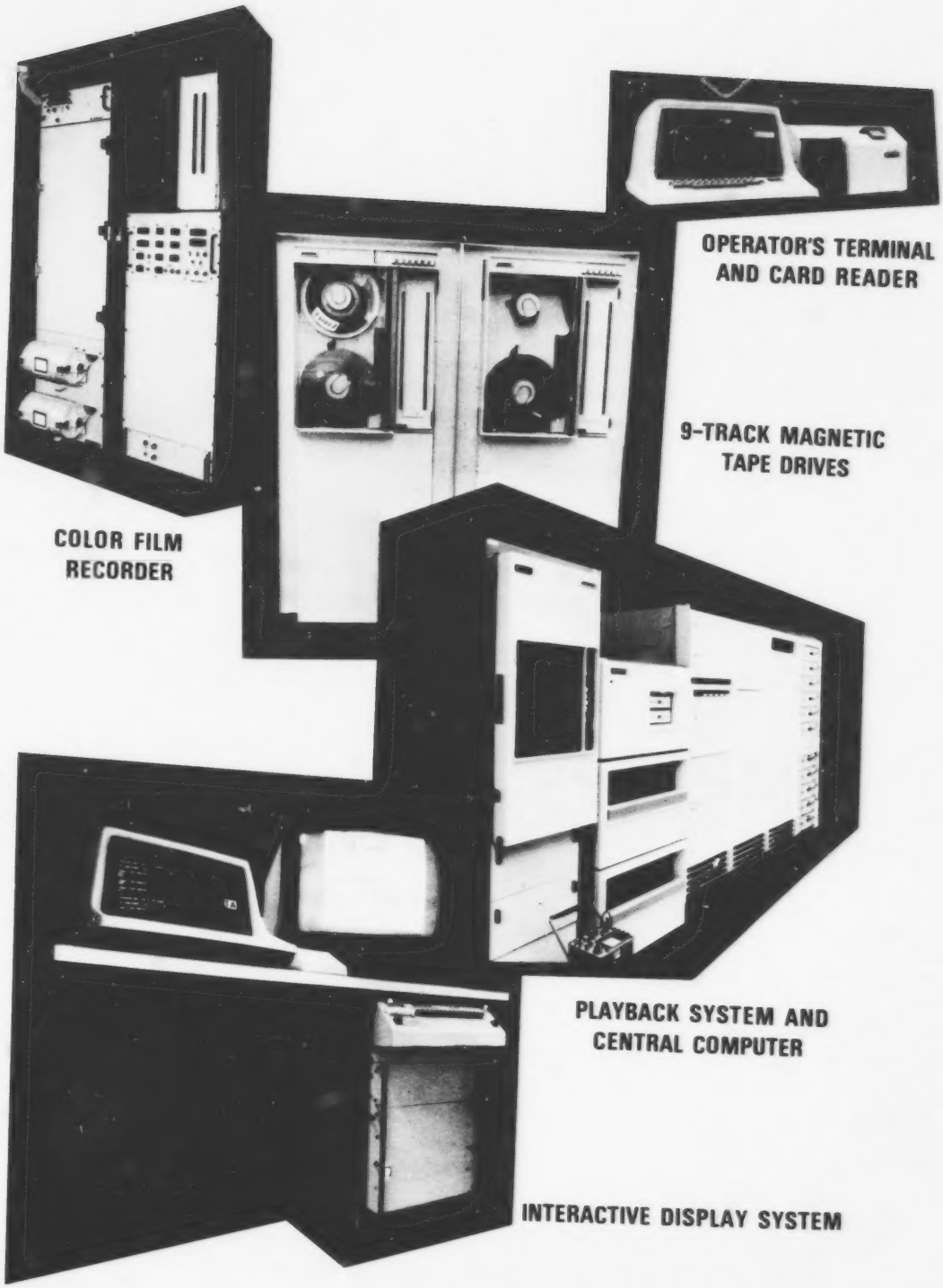

Figure 5. Configuration of the EMSL-LV Data Analysis System.

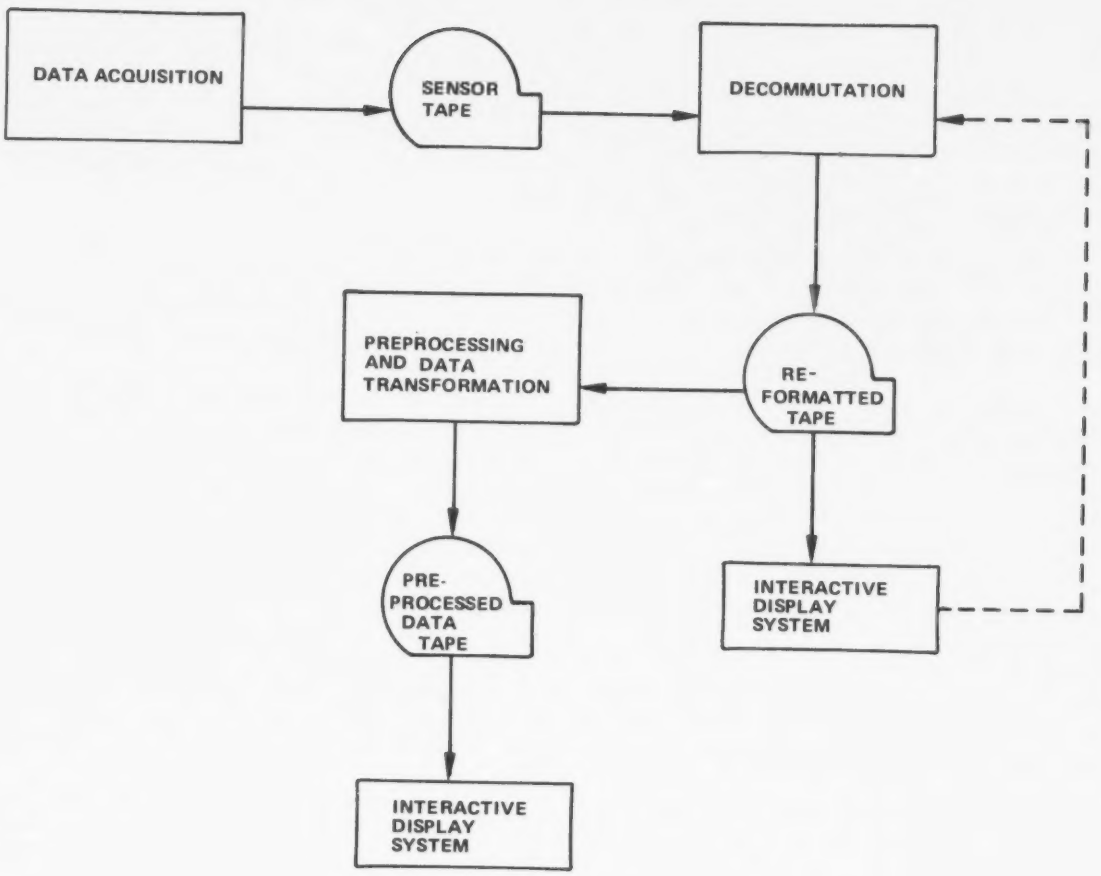

Figure 6. Aircraft multispectral scanner data reduction flow (simplified).

DATA ANALYSIS

Before processing and analysis of the data could be initiated, a land-cover hierarchy similar to Table 2 (photointerpretation hierarchy) had to be developed. This hierarchy (Table 3) is a categorical ranking of the natural or manmade ground features that are of primary interest to the analyst.

In the Phase II operations, it was felt that a Level I/II hierarchy would prove to be more economical and faster for producing the results needed to monitor coal strip mine operations. The Level II hierarchy was implemented whenever the needed ancillary data or photography was available.

Data analysis was begun immediately after the hierarchy was approved. Processing of the aircraft-acquired multispectral scanner data was performed using EMSL-LV developed techniques and hardware for the automatic recognition of spectral patterns.

Analysis of the MSS data proceeded as detailed in Figure 7. A computer-compatible tape that had been preprocessed to remove scanner anomalies was viewed on the Data Analysis System to locate the start/stop picture element (pixel) and the start/stop scan-line numbers for the area of interest. Also during this procedure, a quality check of the data was performed. Following the completion of the aforementioned procedures, the analyst had to decide which classification approach or combination of approaches to use. It was decided to use a combination approach and to classify each data set using a sequential clustering algorithm. The classified image generated by the sequential clustering algorithm would then be used to facilitate the selection of homogeneous training samples for use in other classification approaches to pattern recognition.

The clustering program is an algorithm that groups pixels with similar statistical characteristics. The major assumption in the clustering program is that the data have some homogeneous patterns. Success at running this algorithm requires that the analyst know something about the data, e.g., spectral ranges of the data, approximate number of classes that can be generated, the categories that may possibly cause confusion, the best channels to use for class discrimination, and the number of channels with which to work.

TABLE 2. LAND-COVER CLASSIFICATION HIERARCHY FOR COAL STRIP MINE MONITORING

00 - Active Mine Features

- 01 - Advance cut
- 02 - Topsoil stockpile including embankment
- 03 - Stripping bench, high wall, open cut, pit, and related features
- 04 - Exposed coal seam
- 05 - Raw spoil bank and/or sideslope
- 06 - Coal storage pile
- 07 - Recontoured spoil
- 08 - Haul road including cuts, fills, turnouts, etc.
- 09 - Miscellaneous disturbed areas within active mine complex

10 - Barren Land

- 14 - Shorelines, river banks
- 15 - Badlands (barren silts and clays, related metamorphic rocks)
- 18 - Manmade barrens

20 - Water Resources

- 21 - Settling ponds
- 22 - Pit ponds
- 23 - Undifferentiated ponds, lakes, and reservoirs
- 24 - Water courses, including canals

30 - Natural Vegetation

- 31 - Herbaceous types
- 32 - Shrub/scrub types
- 33 - Savanna-like types
- 34 - Forest and woodland types

TABLE 2. LAND-COVER CLASSIFICATION HIERARCHY FOR COAL STRIP MINE MONITORING (Continued)

40 - Cultural Vegetation (plantations and seedings)

Numerators

41 - Grass/forb seedings
42 - Tree/grass or tree/scrub plantations
45 - Seeding trails and test plots

Denominators

A - Vegetative cover 80 - 100%
B - Vegetative cover 60 - 80%
C - Vegetative cover 30 - 60%
D - Vegetative cover 5 - 30%
E - New seeding, vegetative cover less than 5%

1 - Production level better than native level
2 - Production level about equal with native level
3 - Production level less than native level

50 - Agricultural Production

51 - Field crops
56 - Fallow land

60 - Urban/Industrial

61 - Residential
62 - Commercial and services
63 - Institutional
64 - Industrial
65 - Transportation, communications and utilities
66 - Resource extraction

TABLE 3. MODIFIED LAND-COVER CLASSIFICATION HIERARCHY WITH CODING SYSTEM

LEVEL I LAND-COVER	CODE*	LEVEL II LAND-COVER	CODE	LEVEL III LAND-COVER	CODE
Exposed coal seam	00/04				
Spoil pile	00/05				
Recontoured area	00/07				
Haul road	00/08				
Rehabilitated area	20			Dense vegetation	40/A
				Medium vegetation	40/B
				Light density vegetation	40/C
Natural vegetation	30	Aquatic vegetation	30/31	Dense vegetation	40/A
		Grassland	30/33	Medium density vegetation	40/B
		Forest/woodland	30/34	Light density vegetation	40/C
Agricultural land	50	Planted land	50/51		
		Fallow land	50/56		
Barren land	10				
Urban	60				
Residential	60/61				

*Land-cover classification codes taken from the modified Anderson-Roach Hierarchy.[4]

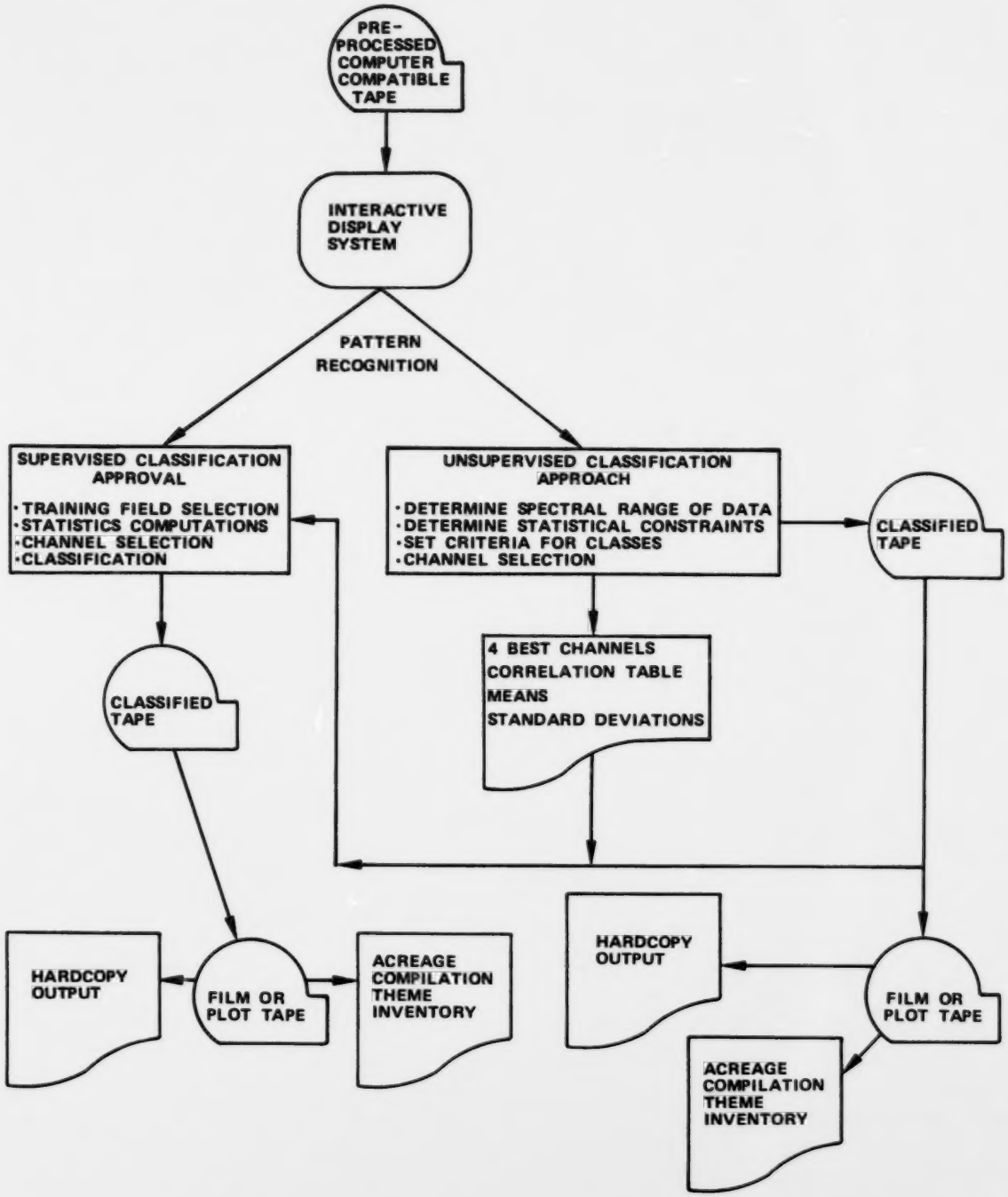

Figure 7. Simplified data processing flow for aircraft multispectral scanner data over coal strip mines.

The data flow for the sequential clustering program proceeds as follows:

- Establishing the initial population (land-cover class),
- Developing statistical profile tables for classes,
- Determining if the picture element belongs to established populations, and
- Establishing additional populations.

Each pixel of the digital data is compared to the existing statistical profiles to determine which population it best fits. When all the pixels have been assigned to one of the active populations or to zero population (pixels exceeding specified count ranges), the run terminates and the results are saved on a 9-track (800 BPI) magnetic tape. Statistics that were generated during the run and stored in the computer are dumped to the line printer device for printing. These hard copies are used in color-coding the images and grouping similar land-cover areas.[5]

After the images are color-coded, a special software program is used to convert the classified digital imagery to a format that is acceptable to the film recorder. The image is filmed in color on a 9- by 9-inch (22.86cm) film format. Contact prints are then produced for use in presentations or reports such as this. The following section presents the land-cover classification images and land-cover acreage statistics.

RESULTS AND DISCUSSION

The aircraft MSS data assessment of the areas affected by strip mining was performed in a single phase analysis through the use of the DAS computer system. The use of the MSS computer-compatible tapes with the DAS provided reliable data in the detection and inventory of strip mines. Results from the computer output were correlated with photography acquired by the EPA lease plane and were found to have excellent size and positional agreement.

The clustering algorithm proved to be very reliable in detecting and distinguishing various earth surface conditions and land-cover situations (mine-related and nonmine-related) in the study areas. The results generated by the clustering algorithm will provide needed information for future planning and data for incorporation into the EPA data base. The data base will be an important tool in the temporal analysis of MSS data. The data reduction and processing techniques developed at this laboratory will furnish additional capabilities and provide a speedy means of strip mine assessment. Also, the acreage compilation algorithm generates reliable statistical data that will be essential in determining the progress of planting and reclamation work of coal strip mines. Presently, no comparative analyses have been performed to determine the correlation between the computer algorithm for calculating acreages and the manual digitizer. However, the dot-count method and the computer algorithm were evaluated and the results differed by 2 percent. The real advantage of the automated procedure is speed. Dot counting is too tedious and time consuming to be utilized in a production atmosphere.

The following sections are devoted to a discussion on the classification results of each of the strip mine studied in this phase of the project.

COLSTRIP COAL STRIP MINE

The Colstrip Coal Strip Mine is located in the south-central portion of Bighorn County, Montana (Figure 8). Colstrip is operated by Western Energy Company and Montana Power. Most of the coal that is produced from this mine is shipped north via a 35-mile rail spur to the Burlington-Northern main line and then to Billings, Montana; St. Paul, Minnesota; and Chicago, Illinois, for steam electric use. Estimated yearly consumption for the electrical generating plants is 4,336,000 tons. The remaining tonnage (500,000 tons) is used to fuel the power plant located in the nearby city of Colstrip, Montana.

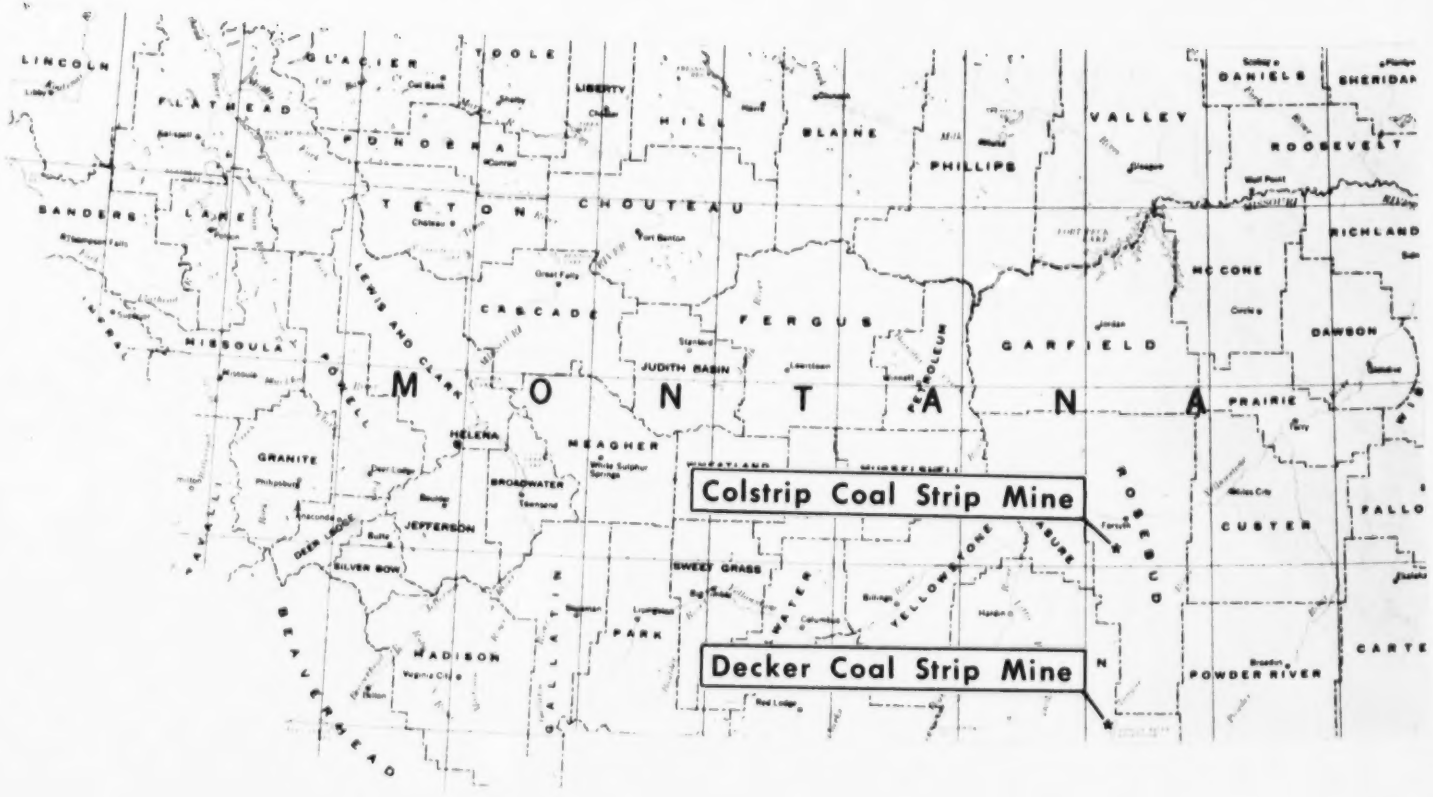

Figure 8. The locations of the Colstrip and Decker Coal Strip Mines within the State of Montana.

The mine has two coal seams (the Rosebud and the McKay) but only the Rosebud is being mined actively now. The Rosebud seam is approximately 27 feet (8.23 meters) in thickness. Reaching this seam requires the removal of 30 (9.14 meters) to 160 feet (48.77 meters) of overburden, averaging around 90 feet (27.43 meters) in thickness.[6]

Vegetation is of the ponderosa pine forest type. This vegetation type occurs mainly in eastern Montana and northeastern Wyoming on uplands, ridges, and north slopes that have shallow loam soils. Prominent species are ponderosa pine, snowberry, bluegrasses, fescues, and June grass. These species are only fairly suitable but have good availability for rehabilitation.

The various vegetation types of the area that were separated by sequential clustering algorithm had to be grouped into three density classes to facilitate color-coding of the classes and to produce a reasonable facsimile of a vegetation map. Note how well the various density classes on the MSS classification image (Figure 9) compare with the aerial photograph (Figure 10). Also, compare the positional accuracy of the coal stock piles and the extent and location of the various water bodies, easily defined by the clustering algorithm, to the photograph. Table 4 provides statistical summaries by class for the entire MSS classification scene.

DECKER COAL STRIP MINE

The Decker Coal Strip Mine is located in Big Horn County, Montana, approximately 25 miles (15.54km) north of Sheridan, Wyoming, and adjacent to the Tongue River Reservoir (Figure 8). Decker is operated by Peter Kiewit Sons, Company, and Pacific Power and Light Company. Coal from this mine is shipped, by rail, to Commonwealth Edison in Havanna, Illinois, for use in generating electricity.

At the present time, the 52 foot (15.85 meter) Dietz No. 1 coal seam is being actively mined. The depth of an active pit varies from 30 to 150 feet (9.14 to 45.72 meters) and requires the removal of approximately 70 to 150 feet (21.34 to 45.72 meters) of sandstone and shale.[6]

Vegetation of this area is the grassland-sagebrush type, which occurs on open grassland of medium and short grass with scattered sagebrush on silty clay-loam soils in southeastern Montana and northeastern Wyoming. Dominant species are as follows: western wheatgrass, crested wheatgrass, blue grama, green needle grass, June grass, winterfat, and Indian rice grass.

Once again the various vegetation types were grouped to facilitate color-coding and to create a less cluttered image. As can be seen from the aerial photograph (Figure 11), a considerable amount of reclamation work has already begun. This is by far the

Figure 9. Land-cover classification map of the Colstrip Coal Strip Mine generated from aircraft-acquired multispectral scanner data.

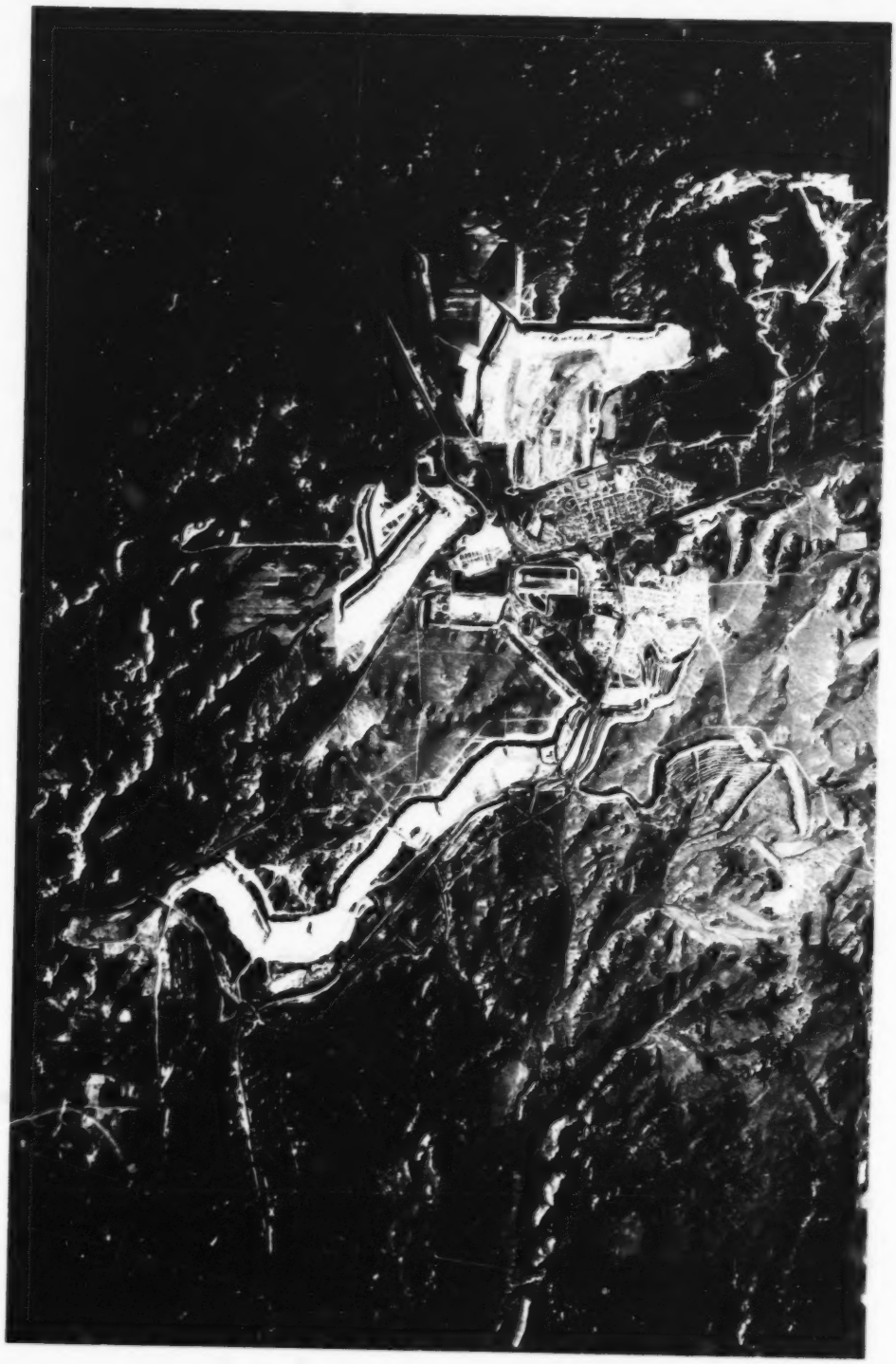

Figure 10. Aerial color-infrared photography of the Colstrip Coal Mine acquired by NASA U-2 aircraft.

TABLE 4. ACREAGE STATISTICS FROM THE ENTIRE SCENE OF THE COLSTRIP COAL STRIP MINE

COLOR	CLASS	PIXEL COUNT	PERCENT	ACREAGE	SQUARE MILES
	Light Density Vegetation	87070	18.72	1269.00	1.98
	Medium Density Vegetation	218973	47.09	3193.00	4.99
	Soil	30101	6.47	439.00	0.69
	High Density Vegetation	71248	15.32	1039.00	1.62
	Exposed Soil	28890	6.21	421.00	0.66
	Ponderosa Pine	11533	2.48	168.00	0.26
	Water	8224	1.77	120.00	0.19
	Coal	8514	1.83	124.00	0.19
	Coal Covered Soil	392	0.08	6.00	0.01

Figure 11. Aerial color-infrared photography of the Decker Coal Strip Mine acquired by NASA U-2 aircraft.

best example of the reclaiming procedure in progress. Note how the mine is proceeding in a westerly direction (as indicated by the location of spoil piles in relation to the coal seam and reclamation work, e.g., recontouring of spoil piles, seeding, fallow, etc.). The reclaimed areas are planted with approximately 8 to 16 vegetation types that occur naturally in the area. This is the reason that grouping the vegetation types is mandatory; otherwise, the image would be too speckled to be of use. Although the reclaimed areas are comprised of the same vegetation species as the surrounding land, the DAS has the capability to allow the areas to be assigned a specific, distinguishable color for ease of discrimination (Figure 12). Table 5 is a statistical summary by classes for the entire MSS classified area.

DAVE JOHNSTON COAL STRIP MINE

The Dave Johnston Coal Strip Mine is located in the east-central portion of the State of Wyoming in Converse County (Figure 13). Dave Johnston Mine is operated by Pacific Power and Light Company and is termed a "captive mine." It is given this name because it ships coal by rail to the Dave Johnston Power Plant located in nearby Glenrock, Wyoming.

The mine has two coal seams that are being mined at the present time. The youngest, the Badger seam, is approximately 16 feet (4.88 meters) in thickness, and the oldest, the School seam, is approximately 37 feet (11.28 meters) in thickness. The average depth of the active pit is about 140 feet (42.67 meters) with a maximum depth of approximately 180 feet (54.86 meters).[6]

Vegetation is of the short-grass prairie type. This type occurs on dry prairies in shallow soils in southeastern Montana and northeastern Wyoming. Dominant species are grama, wheatgrasses, and various needlegrasses. The species that characterize this type have moderately poor suitability and fair availability for rehabilitation.

Both the MSS classified image (Figure 14) and the aerial photography (Figures 15 and 16) verify that an extensive amount of reclamation work has been performed on this westwardly advancing coal strip mine. The coal seam is well defined in the MSS classified image as is the lush vegetation located in the drainage patterns of the area. Most of the transportation network of the mine is well defined; moreover, the road that parallels the western side of the mine also delineates the extent of the active mining area as evidenced by the difference in vegetation densities when moving from west to east on the classified image. Table 6 presents the statistical results from the sequential clustering algorithm classification for the entire MSS scene.

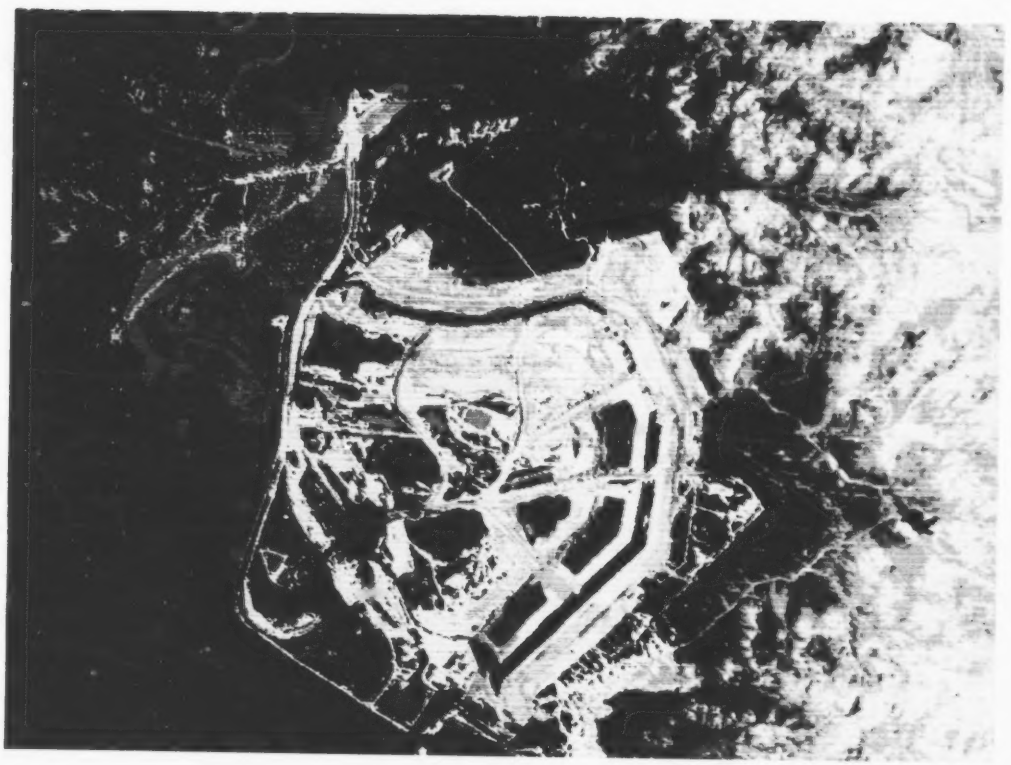

Figure 12. Land-cover classification map of the Decker Coal Strip Mine generated from aircraft-acquired multispectral scanner data.

TABLE 5. ACREAGE STATISTICS FROM THE ENTIRE SCENE OF THE DECKER COAL STRIP MINE

COLOR	CLASS	PIXEL COUNT	PERCENT	ACREAGE	SQUARE MILES
	Light Density Vegetation	16636	7.78	243.00	0.38
	Soil	30317	14.17	442.00	0.69
	Soil	30728	14.37	448.00	0.70
	Water	41331	19.32	603.00	0.94
	Natural Vegetation	75877	35.47	1106.00	1.73
	Reclaimed Area	9323	4.36	136.00	0.21
	Trees	5177	2.42	75.00	0.12
	Agricultural Land	996	0.47	7.00	0.01
	Water	1759	0.82	26.00	0.04
	Coal	1272	0.59	19.00	0.03
	Coal Covered Soil	481	0.22	6.89	0.03

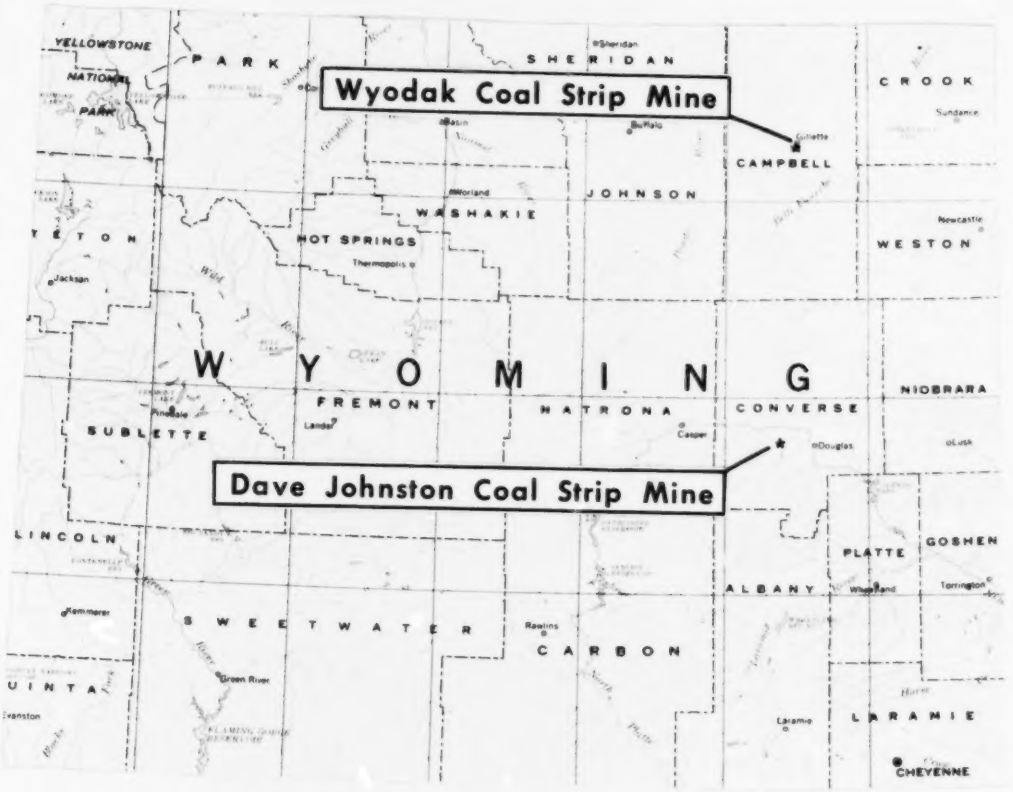

Figure 13. The location of the Dave Johnston and Wyodak Coal Strip Mines in the State of Wyoming.

Figure 14. Land-cover classification map of the Dave Johnston Coal Strip Mine generated from aircraft-acquired multispectral scanner data.

Figure 15. Aerial color-infrared photography of the northern portion of the Dave Johnston Coal Strip Mine acquired by NASA U-2 aircraft.

Figure 16. Aerial color-infrared photography of the southern portion of the Dave Johnston Coal Strip Mine acquired by NASA U-2 aircraft.

TABLE 6. ACREAGE STATISTICS FROM THE ENTIRE SCENE OF THE DAVE JOHNSTON COAL STRIP MINE

COLOR	CLASS	PIXEL COUNT	PERCENT	ACREAGE	SQUARE MILES
	High Density Vegetation	126842	29.40	1849.00	0.89
	Light Density Vegetation	81555	18.90	1189.00	1.86
	Native Grasses	76265	17.68	1112.00	1.74
	Soil	64598	14.97	942.00	1.47
	Soil	47066	10.91	686.00	1.07
	Medium Density Vegetation	30914	7.17	451.00	0.70
	Coal	3692	0.86	54.00	0.08
	Water	295	0.07	4.00	0.01

WYODAK COAL STRIP MINE

The Wyodak Coal Strip Mine is located in Campbell County, Wyoming, approximately 20 miles (32.18km) east of Gillette, Wyoming (Figure 13). Wyodak is operated by Wyodak Resources Development Corporation and produces in excess of 62,000 tons per month. This coal is shipped, via rail, to electrical generating stations in the cities of Osage and Wyodak, Wyoming, and Lead and Rapid City, South Dakota.

Wyodak has two coal seams, the Anderson and the Canyon, which are both approximately 40 feet (12.19 meters) thick. The average overburden thickness is approximately 30 feet (9.14 meters) with the minimum thickness of 15 feet (4.57 meters) and the maximum thickness reaching 40 feet (12.19 meters). The depth of the active pit ranges from 110 feet to 160 feet (33.53 meters to 48.77 meters) with 85 feet (25.91 meters) the minimum depth.

Vegetation is of the short-grass prairie type. This vegetation type occupies dry prairies in shallow soils in southeastern Montana and northeastern Wyoming. Dominant plant species are blue grama, western wheatgrass, and various needlegrasses.

The land-cover classification (Figure 17) of the Wyodak Coal Strip Mine was performed without any problems. The land-cover classes of natural vegetation were grouped for the same reason as cited earlier. Donkey Creek, which meanders through this area, was readily resolved and classified as were the active pit area and the haul roads leading to the tipple. The housing subdivision located north of the western half of the mine was also spectrally distinct, resulting in an urban category for the mine scene. The accompanying aerial photograph (Figure 18) is provided for comparative purposes. Table 7 summarizes the statistical analysis performed on the data.

BLACK MESA COAL STRIP MINE

The Black Mesa Coal Strip Mine is located in the north-northeastern corner of the State of Arizona, in Navajo and Apache Counties (Figure 19). It is operated by Peabody Coal Company headquartered in St. Louis, Missouri. Black Mesa is in the 500,000-and-over tonnage class and strips in excess of 20,000 tons per day. Total tonnage mined in 1974 (last year of available statistics) was 3,933,493 tons. Coal from this mine is transported via pipeline to power plants outside the local area. Average elevation on the lease area is approximately 6,500 feet (1,981 meters), placing it in the pinyon pine/juniper vegetation zone. Dominant vegetation types within the lease area are: pinyon pine, juniper, alkali sacatone, greasewood, snakeweed, sagebrush, blue grama, winterfat, and rabbit brush.

Figure 17. Land-cover classification map of the Wyodak Coal Strip Mine generated from aircraft-acquired multispectral scanner data.

Figure 18. Aerial color-infrared photography of the Wyodak Coal Strip Mine acquired by NASA U-2 aircraft.

TABLE 7. ACREAGE STATISTICS FROM THE ENTIRE SCENE OF THE WYODAK COAL STRIP MINE

COLOR	CLASS	PIXEL COUNT	PERCENT	ACREAGE	SQUARE MILES
1	Bare Soil	63646	24.95	928.00	1.45
3	Light Density Vegetation	95893	37.58	1398.00	2.18
4	High Density Vegetation	48944	19.18	714.00	1.12
5	Natural Vegetation	4044	1.59	59.00	0.09
6	Medium Density Vegetation	34469	13.51	503.00	0.79
7	Agricultural Land	325	0.13	5.00	0.01
8	Disturbed Area	781	0.31	11.00	0.02
9	Water	5369	2.10	78.00	0.12
10	Industrial	614	0.24	9.00	0.01
11	Coal Covered Soil	81	0.03	1.00	0.00
12	Water	55	0.02	1.00	0.00
15	Coal	835	0.32	12.00	0.02
16	Water	85	0.03	1.00	0.00

Figure 19. The location of the Black Mesa Coal Strip Mine within the State of Arizona.

By comparing the classification image in Figure 20 with the aerial photograph in Figure 21 it is easy to verify the validity of the classified image. The most prominent vegetation type, pinyon pine (dark green on the MSS image), is mapped fairly accurately. It was noted that the percent of ground cover for most vegetation species around the mine rarely exceeded 50 percent as evidenced by the white and gray colors that represent exposed soil classes in Figure 21. Note also how the spoil piles located on the western edge of the mine were resolved and classified. Again, Table 8 provides the needed statistical summarization of the classification results by individual classes from the entire scene.

NUCLA COAL STRIP MINE

The Nucla Coal Strip Mine is located in Montrose County, Colorado, approximately 100 miles southeast of Grand Junction, Colorado (Figure 22). Nucla is operated by Peabody Coal Company with headquarters located in St. Louis, Missouri. Nucla is a small strip mining operation and is in the 100,000-to-199,999 tonnage class.

Vegetation of the area is of the pinyon pine/juniper type. Blue grama is the most abundant and frequent understory species. Common species include several gramas, western wheatgrass, galleta, sand dropseed, and June grass. Associated shrubs are often rabbit brush, big sagebrush, snakeweed, and serviceberry.

Figure 23 illustrates that the Nucla Coal Strip Mine is a relatively small operation bordered on the north, east, and south sides by agricultural lands and bordered on the west by its dominant vegetation type -- the pinyon pine/juniper association. This major concentration of pinyon pine/juniper vegetation, as well as small pockets within the scene and other tree species, were easily separated from other vegetation types (Figure 24). The agricultural lands that comprise approximately 50 percent of the scene are planted in alfalfa, which is used as silage by the farmers. Both figures verify that little has been done to reclaim the previously mined areas. Table 9 was prepared to provide the reader with statistical information concerning the result of the classification.

Figure 20. Land-cover classification map of the Black Mesa Coal Strip Mine generated from aircraft-acquired multispectral scanner data.

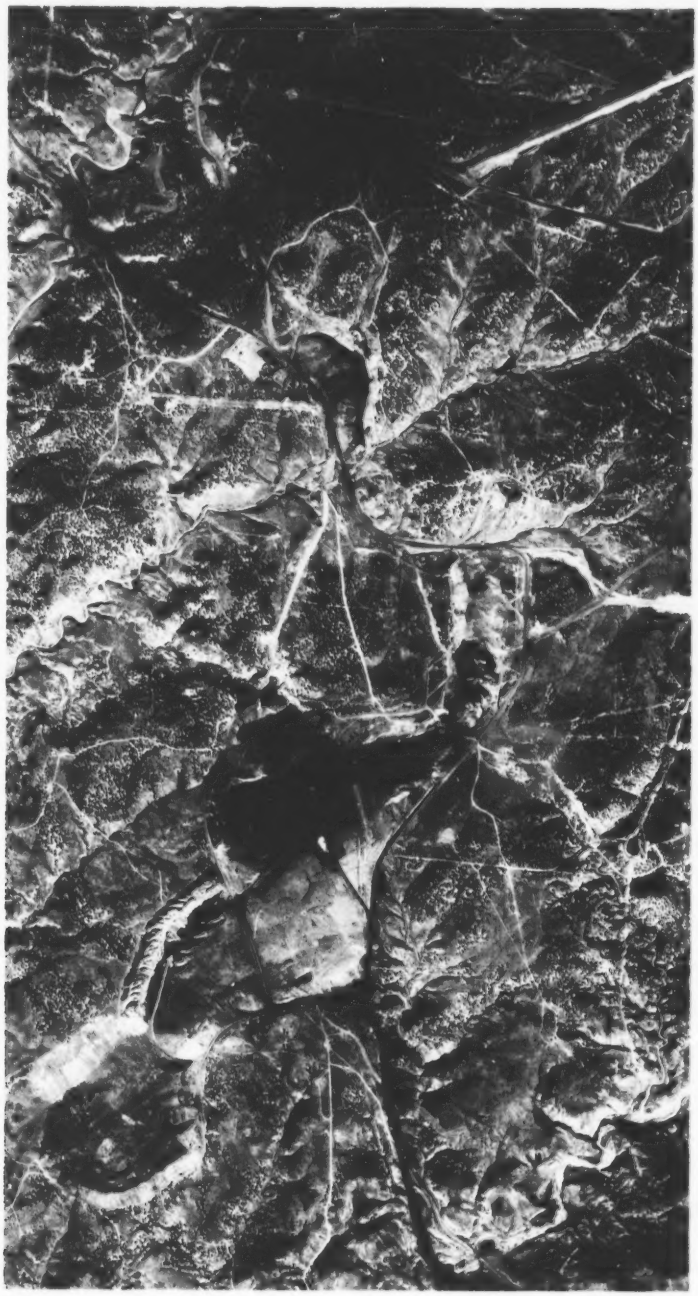

Figure 21. Aerial color-infrared photography of the Black Mesa Coal Strip Mine acquired by NASA U-2 aircraft.

TABLE 8. ACREAGE STATISTICS FROM THE ENTIRE SCENE OF THE BLACK MESA COAL STRIP MINE

COLOR		CLASS	PIXEL COUNT	PERCENT	ACREAGE	SQUARE MILES
	0	Recontoured Area	11049	2.23	161.00	0.25
	1	Bare Soil	60871	12.33	887.00	1.39
	2	Light Density Vegetation	146445	29.66	2135.00	3.34
	3	Medium Density Vegetation	72465	14.56	10.56	1.65
	4	High Density Vegetation	45553	9.23	664.00	1.04
	6	Natural Vegetation	64232	13.01	927.00	1.46
	7	Trees	27960	5.66	408.00	0.64
	8	Coal	15259	3.09	222.00	0.35
	10	Coal Covered Soil	3730	0.76	54.00	0.08
	12	Bare Soil	5339	1.08	78.00	0.13
	13	Bare Soil	39728	8.05	580.00	0.90
	15	Trees	1062	0.22	15.00	0.02

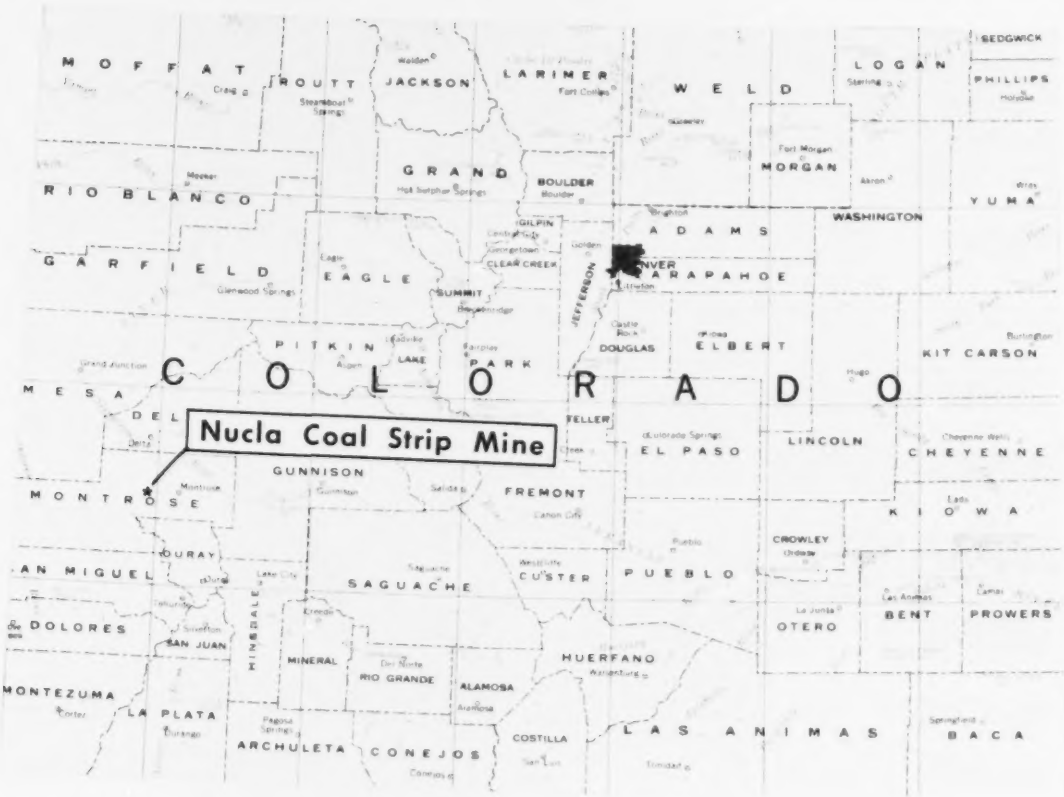

Figure 22. The location of the Nucla Coal Strip Mine in the State of Colorado.

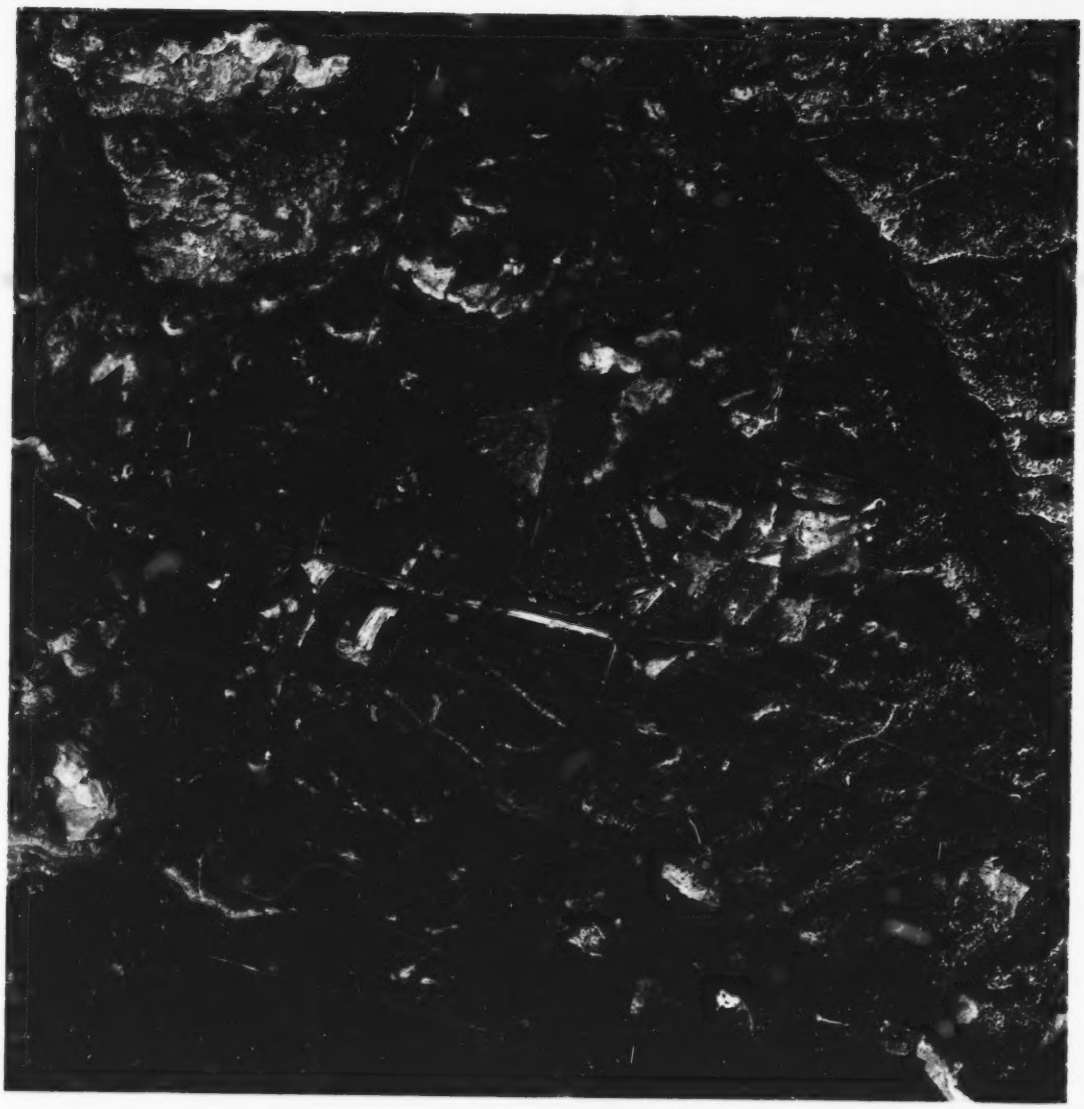

Figure 23. Aerial color-infrared photography of the Nucla Coal Strip Mine acquired by NASA U-2 aircraft.

Figure 24. Land cover classification map of the Nucla Coal Strip mine generated from aircraft acquired multispectral scanner data.

TABLE 9. ACREAGE STATISTICS DERIVED FROM THE ENTIRE SCENE OF THE NUCLA COAL STRIP MINE

COLOR		CLASS	PIXEL COUNT	PERCENT	ACREAGE	SQUARE MILES
	0	Recontoured Area	1509	0.58	22.00	0.03
	1	Trees	51366	19.38	749.00	1.17
	2	Light Density Vegetation	49465	18.65	721.00	1.13
	3	High Density Vegetation	25984	9.80	379.00	0.59
	4	Natural Vegetation	28610	10.08	417.00	0.65
	5	Medium Density Vegetation	34119	12.87	497.00	0.78
	6	Agricultural Land	13487	5.20	197.00	0.31
	7	Agricultural Land	29689	11.22	433.00	0.68
	10	Coal	138	0.05	2.00	0.00
	12	Agricultural Land	30620	11.55	446.00	0.70
	15	Water	152	0.05	2.00	0.00

SUMMARY

In the summer of 1977, aircraft multispectral scanner data and color-infrared photography were collected over six coal strip mines in five western States (Wyoming, Montana, Colorado, Arizona and New Mexico) at an altitude of 12,000 feet (3,660 meters). These data were used by image analysts of EPA's Environmental Monitoring and Support Laboratory in Las Vegas, Nevada, to develop an interactive computer processing procedure for producing "quick turnaround" land-cover classification maps and class acreage statistics for coal strip mines. These classified data sets will serve as the initial input to a geographically referenced data base which will provide a cost-effective means of performing change detection analyses of coal strip mine reclamation activities.

The procedure developed at the EPA laboratory uses a sequential clustering algorithm as an approach to pattern recognition. Basically the clustering program groups pixels with similar statistical characteristics. Each pixel of the digital data is compared to the existing statistical profiles to determine which population it best fits. This clustering procedure is faster and requires less computer time than the training field (supervised) approach to pattern recognition. Also, the classified data set produced by the clustering algorithm can be used to facilitate the selection of homogeneous training fields if an analyst chooses to use the supervised approach to pattern recognition. Overall, this procedure will provide state and federal agencies with an effective and efficient means of monitoring reclamation activities and mine progress and direction.

Finally, the aircraft acquired multispectral scanner data at an altitude of approximately 12,000 feet (3,660 meters) appears to possess sufficient spatial resolution (element size) and spectral resolution (land width and location) for generating land-cover classifications of western coal strip mines using the sequential clustering technique.

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